Expert supervision of flotation cells using digital image processing

Aldo Cipriano, Marcelo Guarini, Alvaro Soto, Hernan Briceño and Domingo Mery

Department of Electrical Engineering, Catholic University of Chile
PO Box 306, Correo 22, Santiago, CHILE
e-mail: aciprian@ing.puc.cl

Abstract

This work describes ACEFLOT, a system for real time analysis of dynamic characteristics of flotation froth, developed for the supervision and control of the copper concentration process. The system uses image processing techniques to measure several physical parameters of the foam that forms on the surface of a flotation cell. It includes an expert system that detects cell malfunctions and low performance operation, suggesting appropriate corrective actions.

1 Introduction

Flotation supervision and control is complex due to its highly nonlinear behavior and the large number of variables involved [1]. It is generally achieved from the information provided by experienced plant operators, who observing the foam that forms at the surface of flotation cells, suggest control actions such as changing the cell level set points and/or modifying reactive doses.

The availability of low cost and powerful computers together with high performance frame grabbers and CCD industrial grade cameras, allow the use of artificial vision to support plant operators in their task of keeping complex industrials processes under control. This work describes ACEFLOT, an instrument to support plant operators in the supervision and control of ore flotation plants, which was developed from the original ideas presented in the ground work described in [2]. The instrument provides up to date information about the state of flotation cells and is capable of suggesting control actions, based on artificial reasoning, using the accumulated knowledge of expert plant operators. The instrument measures the color, size, shape, density, speed and stability of the foam bubbles at the surface of a flotation cell, detecting anomalous situations, and suggests the corresponding corrective actions.

Section 2 of this work provides a general description and capabilities of ACEFLOT, section 3 describes the instrument hardware and software including the expert system operation. Finally, section 4 provides the conclusions.

2 ACEFLOT general description

ACEFLOT is an artificial vision based instrument developed to support plant operators in the supervision and control of mineral flotation process. It determines the color, size, shape and density of the foam bubbles at the surface of a flotation cell. The image color is defined as the mean intensity value of each of the red, green and blue (RGB) image components. The size of the bubbles is defined and computed as the average of the area in cm^2 of all the bubbles appearing in the frame captured by the CCD camera. The shape of the bubbles is defined and computed as the mean ratio between the minor and major axis of each bubble in the image, and finally, the density is computed as the number of bubbles per cm^2 in the image. ACEFLOT also determines the magnitude of the speed and the moving direction of the bubbles, as well as the froth stability. Additionally, it keeps historical register of measured variables and displays current results and tendencies in time.

To the above functional capabilities we have recently added the possibility of detecting process malfunction, such as contaminated foam, open foam, etc., generating corresponding alarms, establishing the possible causes that originated the anomalous state and suggesting corrective actions to overcome the problem.

ACEFLOT has been developed using a standard PC Pentium hardware structure to which a color video frame grabber was added. The software, including a user-friendly interface, the algorithms for computing the relevant variables and the expert system, was developed under a Windows platform using the C++ language. The expert system knowledge base was developed through consultation with expert flotation plant operators.

3 Hardware and software description

ACEFLOT Hardware

Figure 1 shows a schematic view of the hardware structure of ACEFLOT. It consists of:

- Three video acquisition subsystems
- One communication subsystem
- One processing subsystem

Each video acquisition subsystem is enclosed in a hard steel water and dust proof case, which houses an industrial grade color CCD camera, an AC/DC power supply and four special fluorescent lamps, with flat color spectrum, for illuminating the froth surface. The image captured by each camera is transmitted through a double insulated coaxial cable, to the communication subsystem.

The communication subsystem is composed of an analog video multiplexer, a fiber optic link for video transmission and a twisted pair cable used for camera selection. The optical fiber link consists of an electrical/optical converter, the optical fiber and an optical/electrical converter. The video

signal is transmitted from the multiplexer output to the processing subsystem through the fiber optic link.

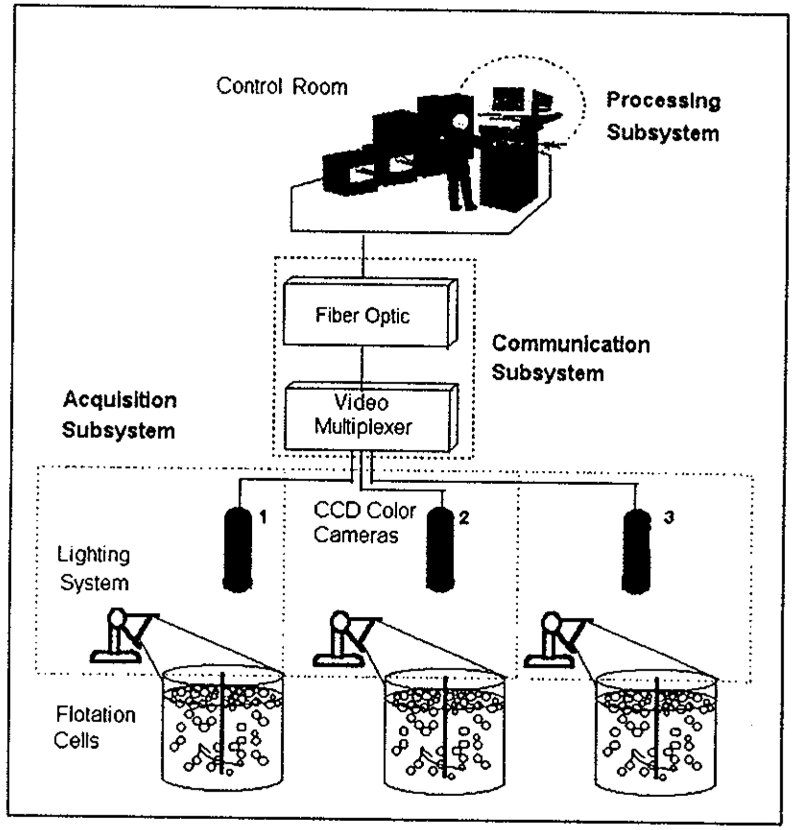

Figure 1: ACEFLOT hardware

The processing subsystem consists of a 100 MHz. Pentium based PC with 32 MB of RAM, a 1.0 GB hard disk, a 17" SVGA monitor and a color frame grabber board that allows to display real time video in the monitor. Because the fiber optic link transmits only one video signal at a time, the processing subsystem selects the video source, using a twisted pair cable connected to an RS-232 port which sends a signal to the video analog multiplexer. A video frame is captured and digitized into memory by the frame grabber. The computer processes the image, displays the results, and stores them on the hard disk.

3.2 ACEFLOT software

The ACEFLOT system software has been developed in C++ to operate under the Microsoft Windows® 3.1 environment in order to provide a friendly interface with selection menus and graphic buttons and on line explanation of functions. Figure 2 shows a general view of the user interface screen, which has three separate and identifiable areas. The first area, on top of the screen, allows the user interaction with the instrument, using menus and icon identified buttons. Through them it is possible to access and activate the diverse functions of ACEFLOAT. Several possibilities are available, such as choosing one of the three flotation cells, showing the video in real time, freezing an image, processing the frozen frame, displaying and storing the results, and so on. The second area on the left of the screen, called processing area, shows the current frame under process. The display reflects the changes generated through the application of the image processing algorithms needed to extract the required information from the image. The third screen area, called the information area, has three sections, one for each flotation cell. Figure 3 shows a detailed view presenting the information corresponding to cell number 2. This window includes a monitor for the real time image of the corresponding cell and shows all the measurements such as the bubbles color, number, size and shape including velocity and stability of the foam. In this window, the user can also display graphs showing tendencies in time of the measured variables, which are obtained from automatically recorded hard disk historic data. It is also possible to display image histograms and to show results from the expert system. As an example figure 4 presents a detailed view showing the histogram of the RGB color components as well as the RGB variations (tendencies) during the last 20 minutes for a given cell.

Through the interface, the user can configure different operating options for the instrument, such as communication port configuration, selection of image processing digital filters, selection of automatic or manual processing, etc.. Running on a Pentium based computer, the software can process and extract all the required measurements from one image in about a minute A whole system, including three cameras, can analyze one cell every three minutes.

3.3 Algorithms

A more detailed discussion of the algorithms used for extracting froth color as well as bubbles number, shapes and sizes, is provided in [3]. A brief description of their operation follows.

To measure the foam color, the software computes the average value of each one of the three (RGB) image color components. Each average value is taken as a measure of the amount of the corresponding color. Through a simple non linear relation [4], the software converts the RGB measure to the most intuitive Hue, Intensity and Saturation (HIS) measure, that can be displayed, instead of the RGB, as an option.

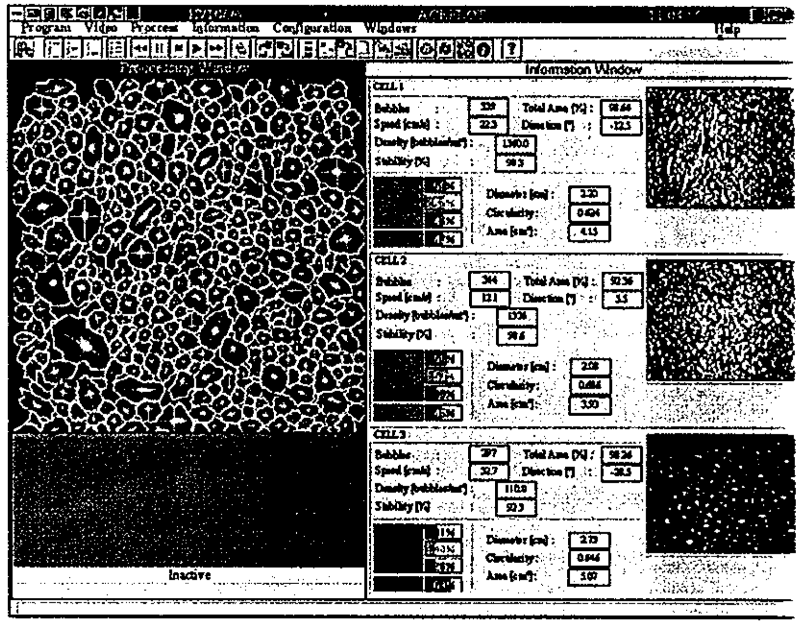

Figure 2: ACEFLOT operation interface

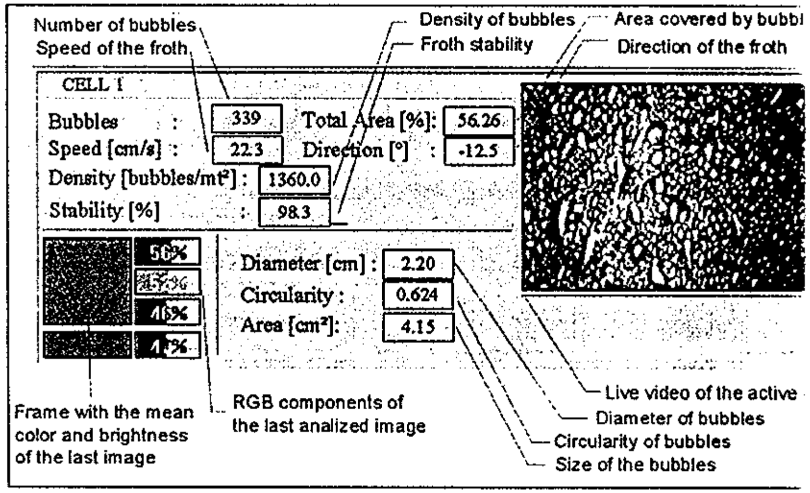

Figure 3: Information window of a single cell

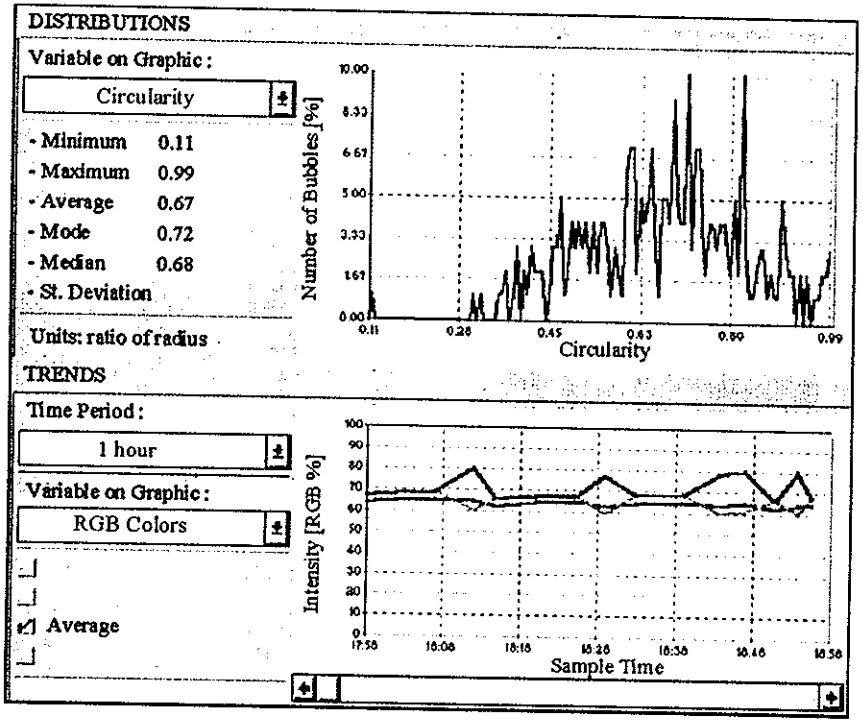

Figure 4: Histogram and trend graph

To determine the size, density and shape of the bubbles, the image is initially low pass filtered to eliminate high frequency noise that perturbs the performance of detection algorithms. The next step localizes the center of the bubbles in the image by recognizing the center of the shiniest zone, which also allows to compute the number of bubbles in the image which corresponds to the number of detected centers. Then, starting from each center, the bubble perimeters are detected localizing the minimum intensity points, looking in several radial directions, towards all the adjacent bubbles. The minima corresponding are then connected with polygons that approximate the bubble's shape, and the individual areas are computed. The minor and major axis of each polygon (bubble) are obtained and their ratios are computed, giving a measure of the bubbles´ shape. A ratio closest to one means circular bubbles, closer to zero means elongated bubbles. Figure 5 shows an image with detected bubble centers and corresponding perimeters and major and minor axis superimposed.

The foam velocity and stability is evaluated through the processing of consecutive images, at a rate of 20 frames per second. The speed is computed determining the movement of bubble centers from one frame to the next, averaging the results of 5 consecutive frames each time. The stability is a measure of the rate of bubble explosions. It is estimated comparing two consecutive image frames, and evaluating a measure of the rate of change in the appearance. Again the results of 5 consecutive

measures are averaged to present the result. Figure 6 shows an image with computed velocity vecto superimposed.

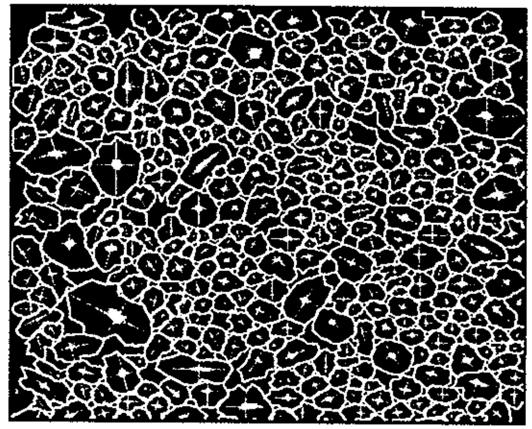

Figure 5: Detection of centers and edges

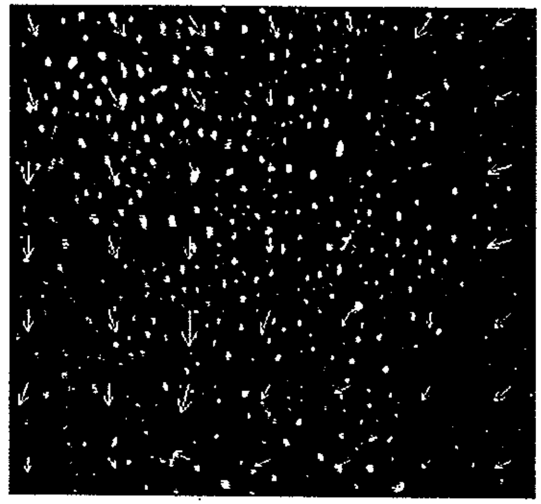

Figure 6: Vectors showing the movement of the froth

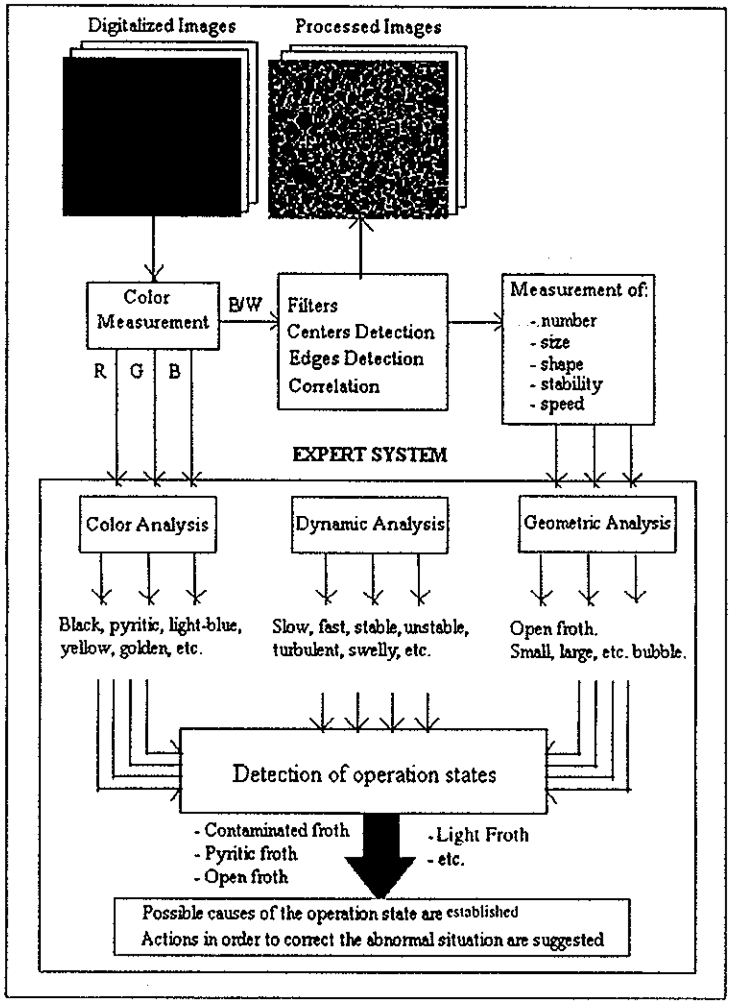

Figure 7: ACEFLOT expert system

3.4 Expert system

The analysis of the captured images together with the information provided by expert flotation professionals, allowed us to design a knowledge base, structured in rules, that determines the operation state of each flotation cell, using the foam color, velocity and stability information, together with the measurements of bubbles density, size and shape.

Figure 7 shows a block diagram of the expert system structure. As shown, the characterization of the cell performance is achieved through the analysis of the foam color, the bubbles geometric characteristics, and the dynamics of the foam. The color analysis allows to obtain the characteristics relative to the coloration of the processed mineral. The geometric analysis allows to define several types of foam such as: fine foam, coarse foam, dense foam etc.. The dynamic analysis allows to characterize the foam speed and stability, distinguishing cases such as slow or fast foam, quiet or turbulent foam, stable or unstable foam.

The foam state characterization is achieved through the processing of *If ...Then* rules in which the measured variables are checked against pre-established threshold levels. Once the cell operation state has been characterized or defined, and in case that it corresponds to an anomalous state, such as open foam or contaminated foam, the expert system searches a table with the possible causes, which in these cases can be an inadequate dose of reactives, foam contamination with external agents such as petroleum, oil, detergents, or a wrong classification in the previous grinding process. Then the expert system suggests the possible corrective actions which the plant operator has to follow in order to solve the problem, such as adjust the dose of reactive, open the cell or reduce the water supply to the process. Figure 8 shows a display corresponding to cell 1 in which the state "Pyritic Froth" has been detected. Figures 9 to 12 present images illustrating some detected operating states, such as open froth, demineralized froth, pyritic froth and contaminated froth.

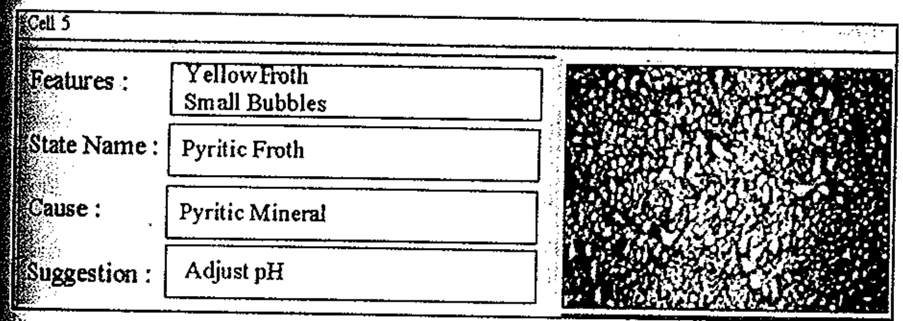

Figure 8: Expert system interface

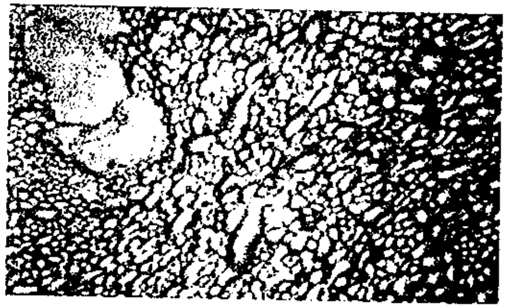

Figure 9: Open froth

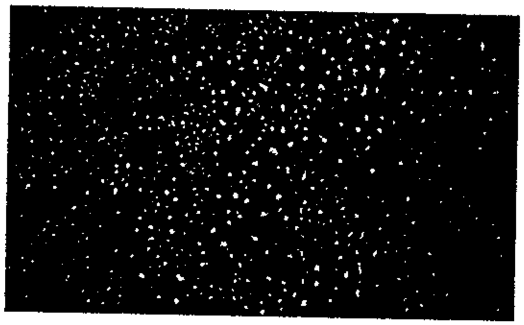

Figure 10: Demineralized froth

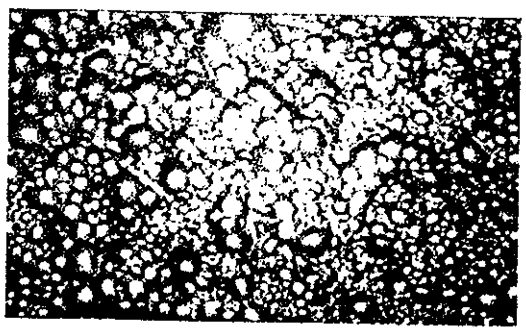

Figure 11: Pyritic froth

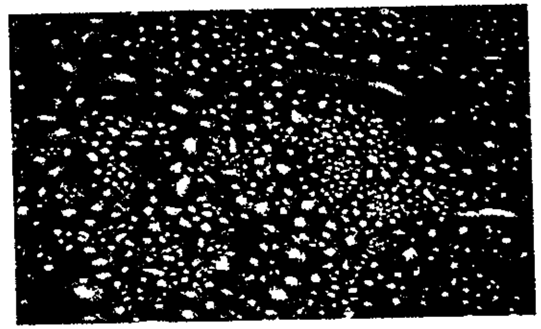

Figure 12: Contaminated froth

4 Conclusions

New hardware and image processing techniques have been combined to develop a low cost instrument to evaluate several physical parameters of flotation froth. It includes a rule based expert system that can recognize possible anomalous operating states, suggesting the required control actions to overcome the problems. A prototype that supervises three cells has been constructed and thoroughly tested during the last 9 months in a large chilean copper mine. Results of these tests have shown that the instrument is not only capable to detect cells malfunction, but also, due to the objective characterization of the foam physical variables, (independent of human observers) is contributing to develop a uniform criteria for taking adequate control actions.

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Development of a synthesiser for the design of flotation networks

Gianni Schena and Massimiliano Zanin

University of Trieste, Faculty of Engineering, DINMA, 34127 Trieste, Italy

Abstract

A process synthesiser for the configuration and sizing of flotation networks has been developed. A brief overview of the strategy for the systematic synthesis of complex multi-stage flotation flowsheets including re-grinding is presented and compared to early attempts. The set of possible network configurations is derived from a general superstructure that features all the potential connections between flotation and regrinding units. The objective function driving the network synthesiser is economic in nature: maximisation of the annual margin = revenue - costs (capital and operating). The original optimisation problem that requires iteration between topological and equipment design variables is decomposed into sub-problems and reduced to the solution of programmes with simpler set of constraints that are solved in sequence.

1 Introduction

1.1 Definition

A flotation-process synthesiser is a software tool that allows the selection of the best design of a flowsheet. This is achieved by systematic generation of alternative flotation flowsheets, their simulation for predicting the metallurgical performances, their ranking according to one or more criteria of preference and the final selection of the best design. The problem is dealt with optimisation methods that find the flowsheet configuration and equipment that maximises an (multi-) objective function reflecting the economic potential of the design solution.

1.2 Motivation

The synthesiser has potential for:

- the design of new flotation plants where number of flotation stages (scalper, rougher, cleaners, re-cleaners and scavengers), the size of the flotation and regrinding equipment and the network configuration should be decided (*greenfield problem*),
- the redesign of operating plants for increasing the efficiency, augmenting the throughput (*debottlenecking*) or decreasing it to minimum production rates (when it is better to maintain